



CHARACTERIZATION OF POROUS METAL MATRICES FOR TRANSPIRATION COOLED STRUCTURES

by R. E. Regan

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

June 1970

Contract NAS 3-12012

THE BUEING COMPANY

Aerospace Group

Seattle, Washington

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INTERIM REPORT

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Contract NAS 3-12012

Technical Management
NASA-Lewis Research Center
Cleveland, Ohio
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FOREWORD

This document reports on an investigation and characterization of porous metal matrices by The Boeing Company as a portion of the "Fundamental Study of Transpiration Cooling", NAS 3-12012, initiated in July 1968. The work was administered under the direction of A. Fortini of the NASA Lewis Research Center.

Boeing personnel who participated in the investigation described herein include J. L. Dutton, Project Leader; J. C. Y. Koh, Technical Leader; and R. E. Regan, Materials Engineer.

The author is indebted to R. W. Evans and B. A. Benson for their advice and assistance in performing the planning and analysis of the test data. The Electron Beam Welding was performed by W. C. Butterfield.

Characterization of Porous Metal Matrices for Transpiration Cooled Structures

by R. E. Regan

ABSTRACT

Porous metal parts produced by two methods, sintered powder and compressed and sintered wire cloth, were characterized so as to assure their suitability for being used in transpiration cooling experimentation.

The methods of characterization included a chemical analysis and an analysis of microstructure and porosimetry data. A description of the characterization methods used is included and the resultant data (porosity, mean hydraulic pore diameter and degree of interconnected porosity) reported.

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1.0 INTRODUCTION

Porous metal parts were procured from a commercial vendor with the intent of having samples with uniformly open porosity so that basic studies relating to transpiration cooling could be conducted. It was essential to the theoretical study that the pore size and pore distribution be closely controlled so that the effects of the matrix could be determined.

Two types of porous metal matrices were procured: (1) a compacted and sintered wireform and (2) a compacted and sintered powder form. Each of these two matrices were procured in three porosity levels (10%, 20% and 40%) and in four thicknesses (1/4, 3/8, 1/2 and 1 inch).

The planned experiment purported to relate the heat transfer and mass flow characteristics of fluids flowing through the metal matrices under both isothermal and diabatic heat flow conditions.

The scope of this report is restricted to the characterization of the porous metal parts purchased under NASA Contract NAS3-12012 and not to their performance as transpiration cooled structures.

2.0 MATERIALS

The specifications for the wireform and sintered powder metal parts required: (1) the porosity fraction (ε) be uniform between parts and within each part to $\pm 1\%$, (2) the chemistry of the stainless steel meet AMS 5511A and the chemistry of the copper parts meet AMS 4701. In addition the specification of the sintered parts required: (1) spherical or nearly spherical particles, (2) particles to be sized so the ratio of the largest to smallest particle not exceed 5:1, and (3) the minimum mean pore diameter be 10, 15 and 50 microns (μ) for the parts of 10, 20 and 40% porosity fraction respectively.

Table I lists all the parts ordered for this study; however the vendor was unable to produce acceptable powder parts. Table I delineates all parts received prior to cancellation of the powder parts.

3.0 EXPERIMENTAL PROCEDURES AND RESULTS

Upon receipt of the sample parts from the vendor the ASG Metal Research personnel performed the following tests to determine whether the parts complied with the specification and to fully characterize the porous matrices:

- a. Visual examination to determine surface cleanliness.
- b. Dimensional and weight check to determine apparent bulk porosity.
- c. Oil impregnation method (ASTM B238-60) to determine interconnected porosity.

- d. Radiographic inspection to determine uniformity of density.
- e. Microstructural examination to determine pore shape, size distribution and uniformity.
- f. Chemical analysis.
- g. Porosimetry analysis to determine pore size, distribution and degree of interconnected: porosity.

3.1 SURFACE CLEANLINESS

Immediately upon receipt of each sample it was viewed under a wide field microscope at 10X magnification to assure that the surface pores were not clogged with foreign particles.

Figures 1 and 2 illustrate the surface appearance of typical wireform and powder samples. It was noted that an occasional foreign particle was found at the surface of several wireform parts but this was at a tolerable level. Ultrasonic cleaning proved to be an effective way to remove these particles.

3.2 APPARENT BULK POROSITY

The apparent bulk porosity of each sample was determined by measuring the part dimensions with a micrometer to ± 0.001 inch and by weighing the entire part on an analytical balance to a sensitivity greater than $\pm .02\%$.

The apparent porosity was computed using the following equation:

$$P_{B} = 100 \times \left[1 - \left(\frac{W \times C}{A \times f \times \rho_{m}} \right) \right]$$
 (1)

where

P = Apparent bulk porosity percent

W = Sample weight in grams

C = Conversion constant $(6.1024 \times 10^{-2} \text{ in}^3/\text{cm}^3)$

A = Sample area in in²

t = Sample thickness in inches

 $\rho_{\rm m}$ = Wrought metal density ($\rho_{\rm m}$ = 8.03 g/cc⁽¹⁾ and $\rho_{\rm m}$ = 8.941 g/cc⁽²⁾)

Table II presents a tabulation of the detail part measurements and the computed porosity.

3.3

DEGREE OF INTERCONNECTED POROSITY

Prior to conducting the detailed porosimetry determinations by the mercury intrusion method, some of the samples (~ 0.18 cc total pore volume) were checked using a Beckman Model 930 air pycnometer to determine the degree of interconnecting porosity. The results obtained with this instrument were erratic because the accuracy of the instrument was only ±.1 cc therefore larger samples were selected (total pore volume .25-1.90 cc) and the oil immersion technique per ASTM B238-60(3) was used.

Samples were cut from the received blocks using an abrasive saw and water soluble cutting oil. After cutting, the samples were degreased in acetone for 30 minutes, water rinsed and oven dried at 400F for I hour. During cutting there was some smearing but the original top and bottom faces were unchanged and provided a continuous free path for the interconnected pores.

After preparation the samples were weighed dry, impregnated with a silicone oil by immersion and drawing a vacuum of less than 50 torr over the container and holding overnight. The oil impregnated samples were weighed after the surface oil was removed by wiping with an oil saturated cloth. Following this weighing the samples were weighed again immersed in water. The apparent bulk porosity and open porosity were computed using the following equations:

$$P = \left[1 - \frac{A}{(B-C)\rho_m}\right] \times 100$$
 (2)

$$I = \begin{bmatrix} \frac{(B-A)}{(B-C)} \rho \end{bmatrix} \times 100$$
 (3)

where

= Apparent porosity in %

= Interconnected porosity in % = Weight of dry sample in grams

= Weight of oil filled sample in grams

= Weight of oil filled sample immersed in water in grams = Wrought metal density ($\rho_{m} = 8.03 \text{ g/cc}^{(1)}$ and $\rho_{m} = 8.941 \text{ g/cc}^{(2)}$).

Density of oil = 1.0952 g/cc (measured).

The results of these determinations are contained in Table 11.

3.4 UNIFORMITY OF DENSITY

Although not specifically called out in the material specification most parts were radiographically inspected using film reading techniques to a 2% sensitivity level. Firm standards were not available for porous metal parts so the establishment of a precise inspection level was not possible, however, this method was able to detect significant density variations within many of the sintered powder samples. Several of the samples were also found to contain cracks.

Using this technique it was possible to select areas of equivalent density to be used for the transpiration study samples, even though there were significant variations within the larger block. This technique did not reveal measurable density variations in the wireform parts.

3.5 MICROSTRUCTURE

Specimens for metallographic examination were prepared by sectioning using an abrasive saw and potting using an epoxy (Marglas). Potting of porous structures must be accomplished very carefully to assure that the pores do not become smeared during polishing and lead to erroneous pore size determination.

The potting techniques employed for these samples involved immersing the parts in a thin Marglas solution, evacuating to less than 50 torr for approximately 18 hours, raising the pressure to one atmosphere and curing at 140F for 8 hours. After the initial potting the samples were rough polished and repotted as before from the polished surface to assure complete penetration of the pores at the surface to be examined.

Following potting the samples were polished in the normal manner. The polished surfaces were then examined, unetched, at magnifications ranging from 5X to 250X. Photomicrographs of typical porous parts illustrating their microstructure are shown in Figures 3 through 8.

In addition to the microstructure of the sintered samples, photomicrographs of the starting woven cloth and raw powders are shown in Figures 1 and 9.

3.6 CHEMICAL ANALYSIS

Chemical analyses of several parts were conducted using spectrographic means to detect all elements except carbon. Prior to submitting the sintered powder samples to the spectrograph the parts were baked overnight in a vacuum of greater than 10^{-4} torr to remove any absorbed gases. Unsintered powder samples were first cold compacted before vacuum baking. Carbon determinations were made using the Leco method. The results of the chemical analyses are presented in Table III.

3.7

POROSIMETRY

The detailed porosimetry determination was accomplished by the mercury intrusion method using the Aminco-Winslow Mercury Porosimeter. This method relies upon the theory that a non-wetting fluid will fill pores only under pressure. The specific relationship between the pore size and the absolute pressure for a mercury porosimeter⁽⁴⁾ is:

$$D = \frac{175}{p} \tag{4}$$

where

D = Pore diameter penetrated in microns

p = Absolute pressure in psia

Small samples (containing a total pore volume of 0.1 to 0.18 cc) were prepared by machining and degreasing in acetone. Only four faces of the sample were machined (the top and bottom faces were untouched) to assure that a free path for the impregnating fluid would remain in a manner such as the samples will be subjected during the transpiration cooling studies.

The machined and cleaned samples were first weighed, placed in a weighed calibrated sample holder and evacuated to less than 50 Å pressure. The sample holder is filled with mercury by immersing the tip of the holder in a glass filling device and raising the pressure to 6.3 psia. At this pressure the filling device is removed and measurements begin. The pressure is gradually increased from 6.3 psia to atmosphere in stepwise fashion and measurements of the mercury column in the calibrated stem recorded. Upon reaching atmosphere, the sample holder assembly is transferred to the high pressure stage and the pressure manually increased to a limit of 15,000 psig stepwise noting the rise of mercury in the calibration stem as before.

By relating the pressure and volume change, the pore size distribution may be plotted on special graph paper. Note that the starting and ending pressures restrict accurate pore size measurements within the range of 80μ to $10^{-2}\mu^{(4)}$. For samples containing pores greater than 80μ a study of the micrographs is required to compute the maximum pore size. For the pores finer than $10^{-2}\mu$, an assumption is made that these are not interconnected.

Figure 10 illustrates a typical data plot for the pore distribution in a wireform sample. The mean pore diameter is defined as that diameter of pores where half of the total pore volume has been penetrated by mercury. While this characteristic diameter has no direct relation to the mean hydraulic pore diameter (D_{HM}) it is conveniently measured and serves as a first approximation to the D_{HM} .

It must be noted here that several problem areas were encountered: (1) the low density wireform parts all had mean pore sizes greater than 100 Å, therefore, the porosimetry was useless for these samples and (2) mercury wets copper, hence the basic premise for a non-wetting fluid invalidates measurements made on copper parts.

In the performance of these tests alternative methods were chosen. The wireform structure was highly repetitive and regular for the low density samples, therefore, an analysis of the microstructure permitted accurate measurements.

The sintered copper parts were rejected because of excessive oxygen contamination and non-uniform microstructure, therefore, porosimetry studies were not conducted on these samples. If, however, they were to have been conducted two approaches were considered:

(1) to analyze the microstructure and make measurements based upon the micrographs or

(2) internally oxidize the samples to prevent wetting and compensate for the thickness of the oxide film.

3.8 COMPUTATION OF THE MEAN HYDRAULIC PORE DIAMETER

The most important characteristic of a matrix for transpiration cooling determinations is the mean hydraulic pore diameter and not the mean pore diameter given by the mercury porosimeter. This characteristic is defined by the following relationship and can be computed from the porosimeter data.

$$D_{HM} = 4 \frac{\varepsilon}{R}$$
 (5)

where

 D_{HM} = Mean hydraulic pore diameter

 ε = Porosity fraction of interconnected pores per unit volume of matrix $\boldsymbol{\beta}$ = Surface area of open pores per unit volume of matrix

Based upon the work of Carman⁽⁵⁾ the equivalent pore diameter (D_e) is defined by the following equation:

$$D_{e}^{2} = \frac{1}{\varepsilon} \int_{0}^{\varepsilon_{p}} (D_{e_{i}})^{2} d\varepsilon_{p_{i}}$$
 (6)

and

$$D_{HM} = 4 \frac{\lambda d}{b_d} D_e$$
 (7)

where:

= a shape factor (~ 1 , experimentally verified by Evans⁽⁶⁾)

b_d = a shape factor (4 for cylinders)

εpi = incremental porosity fraction of interconnected pores per unit volume of matrix penetrated by mercury

D_e: = incremental pore diameter from mercury penetration data.

Utilizing the porosimeter data for the relationship between $(D_e)^2$ and ϵ_p after extrapolating the data to include those pores greater than 80 μ , the computation of the hydraulic

pore diameter (D_{HM}) was performed as follows: Plot the penetrated void volume/total penetrated void volume (p_i) and the square of the pressure-pore size relationship (equation 4) on semilog graph paper. Numerical integration was employed to determine the approximate solution to equation 6.

$$\Delta_A = (\varepsilon_{p_1} - \varepsilon_{p_2}) \left(\frac{D_{e_1} + D_{e_2}}{2} \right)$$
(8)

$$D_{e} = \left(\frac{1}{\varepsilon_{p}} \times \sum_{o}^{\varepsilon_{p}} \Delta_{A}\right)^{1/2} \otimes D_{HM}$$
(9)

Because the porosimeter results were valueless for the low density wireform parts, the hydraulic diameter was calculated from the geometric values computed from the photomicrographs in the same manner as Evans(6,7). This method uses the relationship stated in equation 5. The pore fraction is essentially the same as the bulk porosity because all pores are interconnecting (see Table II) or can be computed from the part geometry assuming smooth surface wires. The surface area of the pores is the same as the surface area of the wires after compensating for the surface area removed due to contact of crossing wires. The number of lengths of wires and number of wire crossover contacts per unit volume provides sufficient data to compute the hydraulic pore diameter.

The same analysis as used by Evans was written into a Boeing Blitz computer program and the data for all the wireform parts computed. From the photomicrographs (Figures 4 through 6), it is evident that as the density increased the heterogeniety of the structure increased and some adjustment had to be made for the samples containing 10% and 20% porosity. This was accomplished in the same computer program using the same criteria established by Evans⁽⁷⁾.

The mercury penetration method differs from the metallographic method insofar as the mercury porosimetry data permits a direct measurement of the hydraulic pore diameter whereas the metallographic (geometric) method permits a direct measurement of the internal surface area (β). The relationship given by equation 5 was used to convert from a pore diameter to a surface area or vice versa and both values are presented in Table II.

The accuracy of the geometric method to determine pore size and total porosity is strongly dependent upon the selection of a truly representative micrograph. Because of the nature of the wireform structure this can best be accomplished by means of a transverse section. However, because the total porosity data is not in close agreement with the bulk part measurements and the appearance of non-uniformity of microstructure apparent in the micrographs, it must be concluded that the analysis of a single micrograph to determine the warp and weave wire spacing and the layer thickness is not adequate for this material. Several metallurgical sections must be analyzed to achieve representative values.

The geometric analysis used was unique to the wireform structure; however, in a subsequent report which will be primarily concerned with powder compacts the method developed by Smith and Guttman⁽⁸⁾ will be employed.

3.9 ASSEMBLY OF SAMPLES TO SAMPLE HOLDERS

Although not specifically a part of the matrix characterization, the method of the joining the porous samples into the wrought sample holders is discussed for general interest.

Acceptable samples were machined into 3/4 inch diameter cylinders with a 3° taper on the side wall by conventional means. The metal smearing which occurred on the cylinder walls was inconsequential because the parts were joined to a solid sample holder.

After machining the samples and holders were assembled and placed under an electron beam and welded in vacuum at the rate of 20 rpm using a 31 kv, 95 ma power setting. Figures 11 and 12 illustrate the top and bottom views of test welded assemblies along with a transverse section through the joint.

The large holes in the weld in Figures 11 and 12 are not porosity but rather a section through a portion of the pressure probe hole which was drilled into the sample holder prior to welding. The smaller holes near the toe of the weld (top of photographs) is porosity but the extent is inconsequential to the performance of the weld and to the degree of sealing accomplished. Note that a crack developed in the sintered powder sample adjacent to the pressure probe hole as a result of the high residual stresses inherent in the design. It is therefore, imperative that the pressure probe hole be drilled after welding rather than before welding.

Wireform 304 stainless parts used in this study can be successfully joined to wrought 321 sample holders by electron beam welding. Welding of sintered powder parts appears feasible but is more difficult than the wireform material.

The pits apparent in the wrought 321 sample holder (right half of cross section views) are indicative of a fairly "dirty" heat of steel which was obtained.

4.0 CONCLUSIONS

- 1. The wireform parts received under subcontract are acceptable for further study as transpiration cooled matrices. The sintered parts are not acceptable and have been rejected.
- 2. Porous metals may be characterized in terms of the mean hydraulic diameter by either interpretation of micrographs or by the mercury intrusion methods; however, each has some limitations:
 - a) The micrograph selected must be truly representative of the structure being analyzed.
 - b) The analysis of micrographs to determine the hydraulic pore diameter is a lengthy process.
 - c) The micrograph cannot distinguish between total porosity and interconnected porosity.
 - d) The mercury intrusion method gives a result based upon a much larger sample than does the micrographic method.
 - e) The mercury intrusion method is not suitable for characterizing structures with large pores since the upper limit of resolution os approximately 80.
 - f) The mercury intrusion method cannot be used where a chemical reaction will take place between the mercury and the porous metal part. It is possible, however, to analyze a copper sample by the mercury intrusion method by pre-oxidizing the copper but an allowance must be made for the thickness of the oxide film.
- 3. The mercury penetration method is the preferred characterization method where it can be used and the micrographic method should be used primarily as a cross-check or as an alternate method for structures with large pores.
- 4. The wireform parts exhibited increasing degrees of heterogeniety with increasing density but were acceptable because they are representative of the particular process used.
- 5. The heterogeniety of all of the porous parts appeared to be relatable more to the density than the thickness.
- 6. The mercury porosimeter is not suitable for characterizing wireform parts with a porosity fraction greater than approximately 20%.
- 7. The wireform parts investigated in this program are readily joinable using electron beam welding but the sintered powder parts have a marginal weldability.
- 8. Discrepancies in the data reported by the various techniques are due in part to the heterogeniety of the samples and the size of the specimens used.

5.0 REFERENCES

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TABLE I
POROUS MATRICES REQUIRED FOR TRANSPIRATION COOLING STUDY

<u>Material</u>	Microstructure	Nominal Porosity	Nominal Thickness	Samples Received
304	Wireform	10%	0.250	R102-1
Stainless			0.375	R103-1
Steel			0.500	R104-1, R104-2
]			1.000	R108-1
		20%	0.250	R202-1
			0.375	R203-1
			0.500	R204-1
			1.000	R208-1
		40%	0.250	R402-1, R402-2
		•	0.375	R403-1
			0.500	R404-1, R404-2
			1.000	R408-1, R408-2
		201	2 272	
	Sintered Powder	10%	0.250	None
			0.375	None
			0.500	None
			1.000	None
		20%	0.250	S202-1
			0.375	S203-1
			0.500	S204-1
			1.000	None
		40%	.0.250	S402-1, SC402-1 thru 5*
			0.375	S403-1, SC403-1 thru 6*
			0.500	S404-1, SC404-1 thru 6*
			1.000	SC408-1 thru 4*
I		3 <i>cct</i>	0.050	g100 1
Oxygen Free		10%	0.250	C102-1 C103-1
High			0.375 0.500	C103-1 C104-1
Conductivity			1.000	None
Copper		•		
1		20%	0.250	C2O2-1
			0.375	0203-1
			0.500	C204-1
1	Topogo de la companya		1.000	None
		40%	0.250	C402-1
		- •	0.375	C403-1
			0.500	None
J) *		1.000	None

^{*} Samples "SCxxx" were die compacted to 1.4" dia. All other samples were supplied as 2 1/2 inch square blocks.

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3	3 12	5	11.6	8.7	ı	1	19.4	19.8	18.7	1	ı	- F	36.9	,	8.0	ı	ı	19.2	1	9.9	1		39.2	1	1	1	1			1	١
ASTM 8238-60	Inter. Com. Persuity (%)	7.03		8 0.6	ļ		91.1	1	1	1	92.4	ı	9.98	86.4		1	ı	8.6	6.83	84.3	55.7	1	95.7	63.0	76.9	71.5	82.0	\$0.5	90.0	87.0	7.8
ASTM	S Section 1	90.0	ı	8.70	1	ı	18.5	1	ı	1	35.1		39.9	38.3	ı		1	19.5	20.3	17.4	37.7		38.6	0.11	6.8	m.	19.51	19.71	19.41	37.8	37.8
	Apparant Parasity (%)	9.2	9.5	8.7	9.3	6.3	19.5	6.61	20.02	20.3	37.2	1.08	39.9	37.8	80.8	38.3	38.5	19.2	30.6	18.6	38.3	38.9	39.2	e. e.	7.5	8.0	18.6	19.2	20.2	37.7	39.9
STIN	Apparate Demaity (g/cc)	7.285	7.267	7.335	7.281	7.283	6.466	6.432	6.422	6.402			4.82	4.999	4.754		4.938	6.492	6.3%	6.339	4.954	4.909	4.882	8.144	8.272	8.72	7.282	7.22	7.135	5.568	5.453
BULK PART MEASUREAENTS	Weight Grame	168.65	278.67	342.35	389.47	804.2	181.2	251.3	341.4	200		~		25.919	248.51	8.510	743.16	166.14	223.70	307.62	145.11	158.22	238.66	238.04	278.79	495.26	182.00	262.88	346.94	153.02	171.43
PART ME	Width (Inch)	2.51	2.50	2.50	2.52	2.98	2.50	2.50	2.50	3.8	585.	2.50	.516	\$3.	2.50	13%	2.77	2.51	2.50	2.30	2.48	2.51	2.49	2.50	2.50	2.50	2.51	2.52	2.51	2.51	2.51
BUK	(A-A)	2.51	2.30	2.50	2.52	2.78	2.50	2.50	2.50	2.77	1.061	2.50	1.00	- 8	2.51	819.	3.02	2.51	2.50	2.50	2.49	2.51	2.50	2.50	2.50	2.30	2.51	2.51	2.51	2.51	2.51
	chowes sects)	5	574	83	14	112	74	82		8	28	49	112	89	8	ब	8	200	42	65	8	=	8	38	8	87	142	8	5	*	8

CHARACTERIZATION RESULTS OF POROUS METAL MATRICES

Dote appears to be in core.

Dote appears to be in core.

12

Sangala

R102-1 R104-1 R104-1 R202-1 R202-1 R402-1 R402-1 R406-1 R406-1 R406-1 S202-1 S203-1 S203-1 C202-1 C2

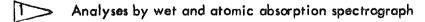
TABLE III

CHEMICAL ANALYSES OF POROUS METAL MATRICES

AISI TYPE 304 STAINLESS STEEL

Element	R202 3	R203	R404	<u>5203</u>	<u>\$403</u>	Powder
Cr	19.00%	20.00%	18.75%	18.60%	18.61%	18.96%
Ni	9.82	9.85	9.68	11.02	10.54	10.70
С	. 055	.04	. 04	. 08	. 07	,005
Mn	1.16	1.30	1.24	. 15	.11	.11
Si	. 60	. 50	.50	.91	. 86	. 92
S	.020	.015	. 009	. 0085	. 008	. 029
P	. 020	.027	-	.006	.011	.011
Fe	Balance	Balance	Balance	Balance	Balance	Balance

Element	Powder	<u>C102</u>	<u>C103</u>	<u>C204</u>	C403
Cu	96.2%	93.4%	98.8%	99.3%	98.8%
Ag	. 0850	.5	.5	.5	.5
O	2.02	. 0955	.1940	. 1375	. 2684
Pb	.3400				
Sn	.3180				- Notes
Ca	. 0750	. 0453	.0153	. 0168	. 0374
K	.1140	.0022	.0005	. 0005	. 0004
P	-	.0031	.0013	. 0028	***************************************
Cl T	.0100	.0066	.0043	.0035	.0220
F 🗂	.0330	.0297	. 0866	. 0289	. 0455
Al	.1330	.0456	. 0290	.0226	.0138
Na	.0660	. 0547	.0048	.0061	.0219
Si	.1830	.7544	.2851	.0115	. 1450
С	.1810	.0180	.0473	.0134	.1065
N.	.0015	.0055	.0037	. 0058	.0188
Н	. 0025	.0006	.0010	.0008	.0031



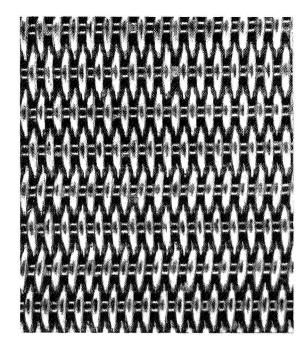
2 Analyses by mass spectrograph

Sample code Rxxx - Wireform matrix

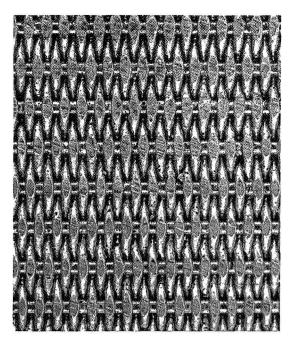
Cxxx - Sintered copper powder matrix

Sxxx - Sintered stainless steel powder matrix

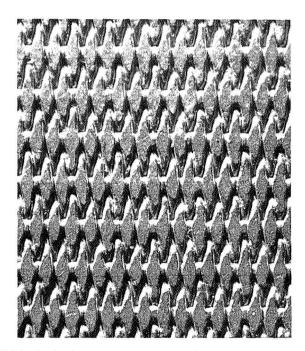
1st 2 digits denote nominal porosity – last digit denotes thickness in 1/8 inch



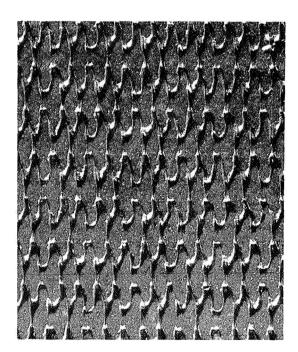
ORIGINAL WOVEN CLOTH



ROLLED AND SINTERED TO 40% POROSITY



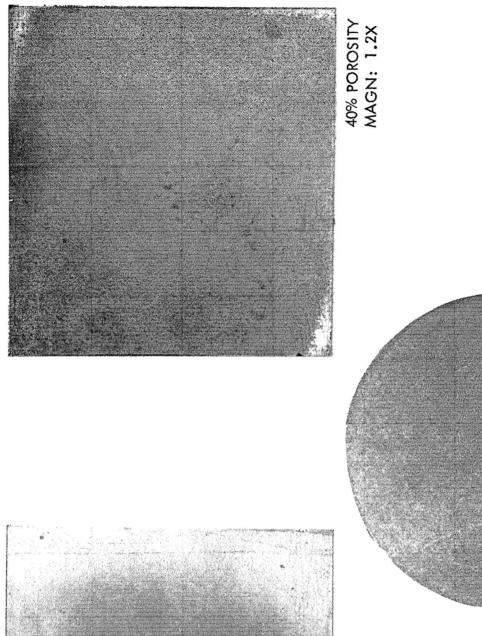
ROLLED AND SINTERED TO 20% POROSITY

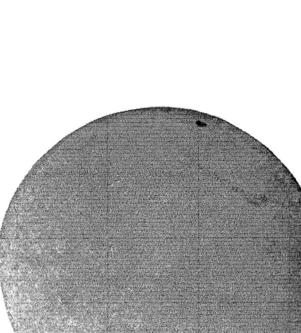


ROLLED AND SINTERED TO 10% POROSITY

MAGNIFICATION: 10X

FIGURE 1 SURFACE APPEARANCE OF POROUS 304 CRES WIREFORM PARTS





SURFACE APPEARANCE OF POROUS SINTERED STAINLESS STEEL POWDER COMPACTS FIGURE 2

40% POROSITY MAGN: 2.4 X

10% POROSITY MAGN: 1.2X

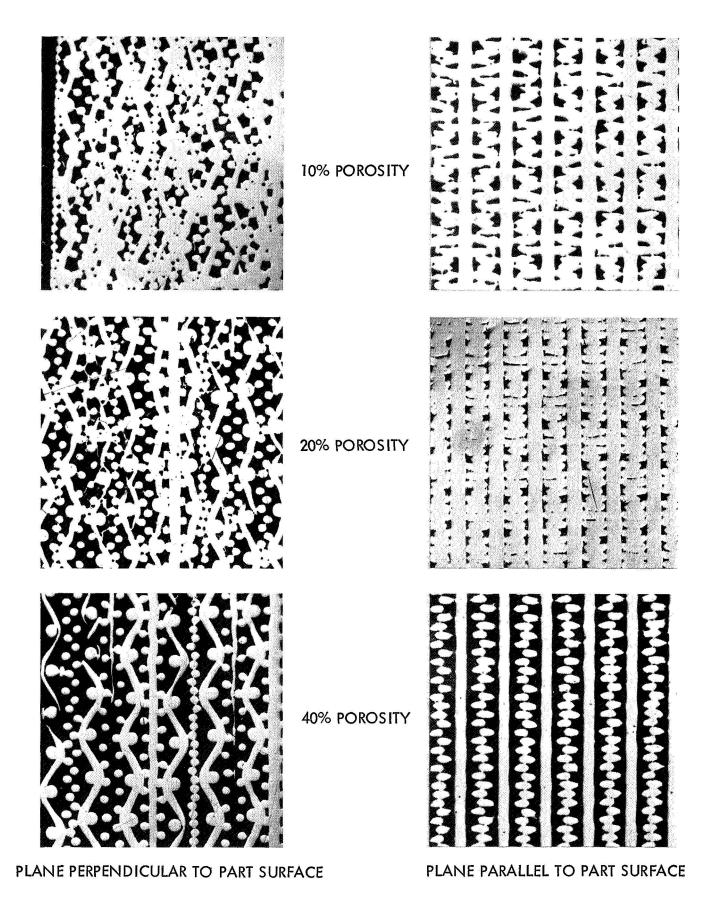


FIGURE 3 POLISHED VIEWS OF POROUS 304 CRES WIREFORM PARTS MAGNIFICATION: 10X

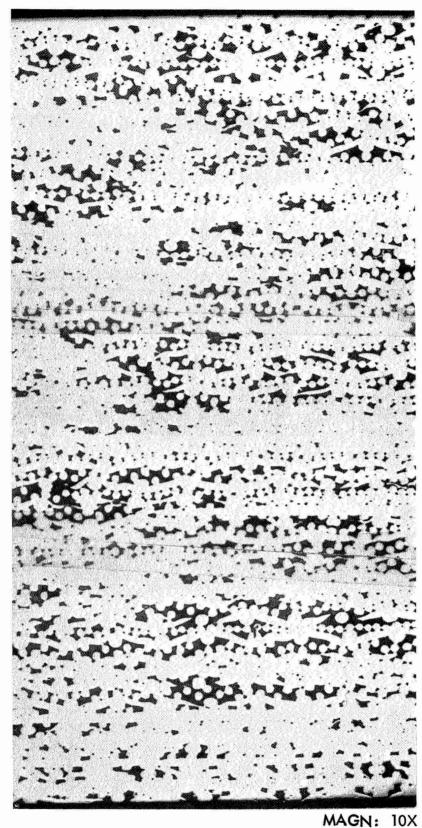


FIGURE 4 TRANSVERSE SECTION THROUGH 1-INCH THICK POROUS 304 CRES WIREFORM PART ROLLED AND SINTERED TO 10% POROSITY

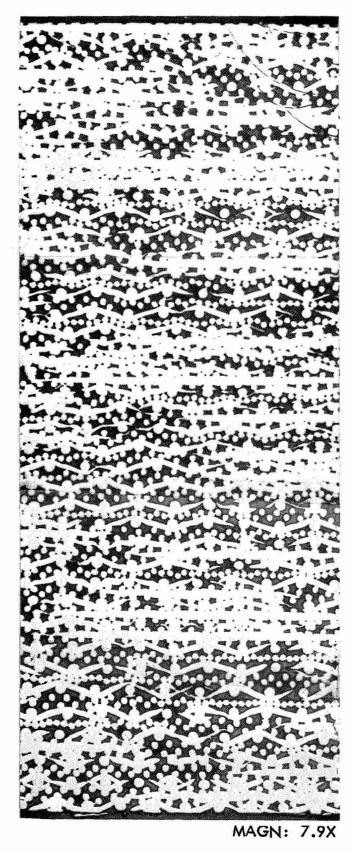


FIGURE 5 TRANSVERSE SECTION THROUGH 1-INCH THICK POROUS 304 CRES WIREFORM PART ROLLED AND SINTERED TO 20% POROSITY

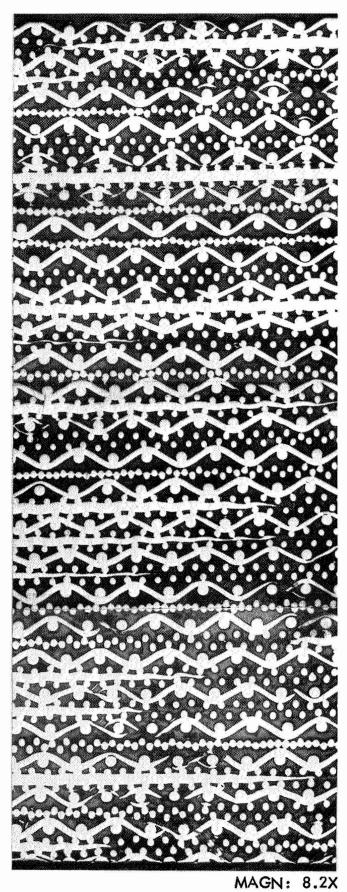
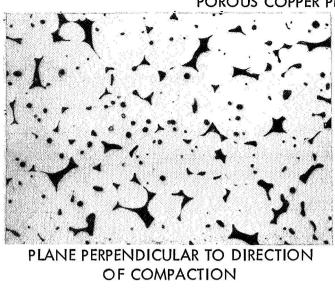


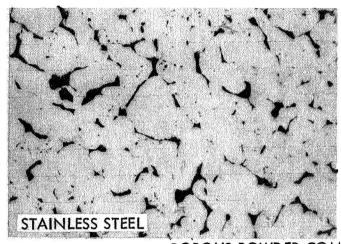
FIGURE 6 TRANSVERSE SECTION THROUGH 1-INCH THICK POROUS 304 CRES WIREFORM PART ROLLED AND SINTERED TO 40% POROSITY

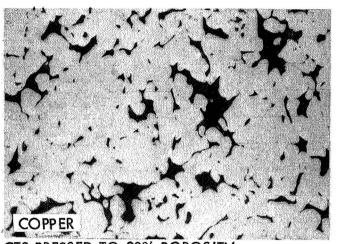
POROUS COPPER PRESSED TO 10% POROSITY



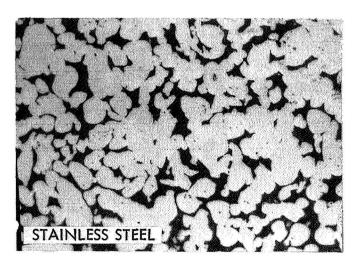
PLANE PARALLEL TO DIRECTION

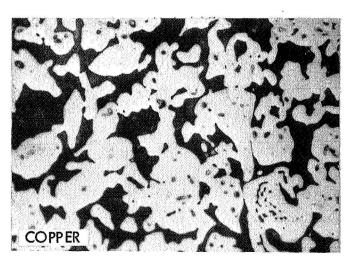
PLANE PARALLEL TO DIRECTION
OF COMPACTION





POROUS POWDER COMPACTS PRESSED TO 20% POROSITY PLANE PERPENDICULAR TO DIRECTION OF COMPACTION

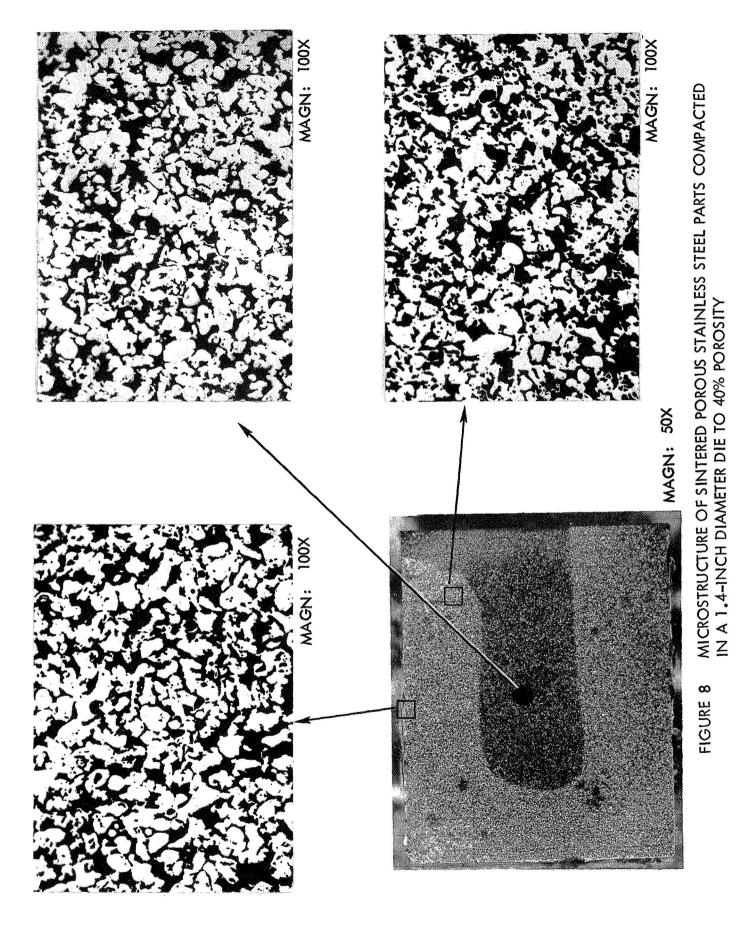


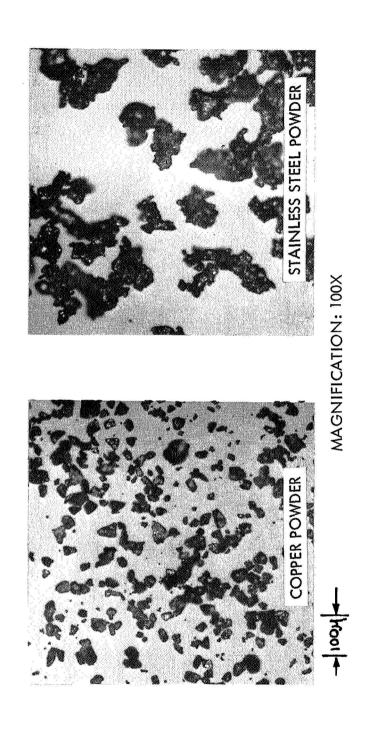


POROUS POWDER COMPACTS PRESSED TO 40% POROSITY PLANE PERPENDICULAR TO DIRECTION OF COMPACTION

FIGURE 7 MICROSTRUCTURE OF POROUS SINTERED POWDER COMPACTS

MAGNIFICATION: 250X





REFLECTED LIGHT PHOTOMICROGRAPHS OF POWDERS USED FOR POROUS SINTERED POWDER PARTS FIGURE 9

POROSITY DETERMINATION

(By 5-7107 or 5-7108 Aminco-Winslow Porosimeter)

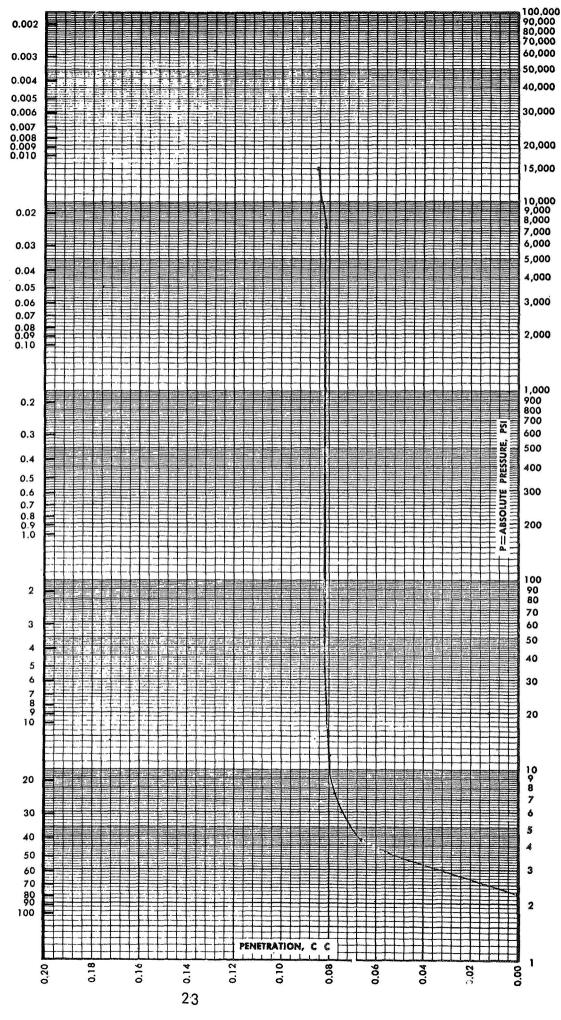
TYPICAL MERCURY PENETRATION DATA CURVE

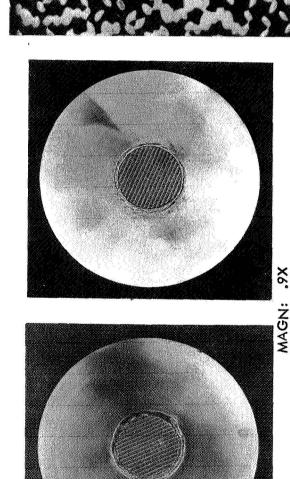
FIGURE 10

12-11-68 R 203 SAMPLE DATE

WT. OF SAMPLE, G. 4.8792

D=PORE DIAMETER (MICRONS)





MAGN: 10.8X

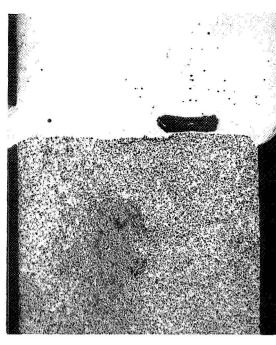
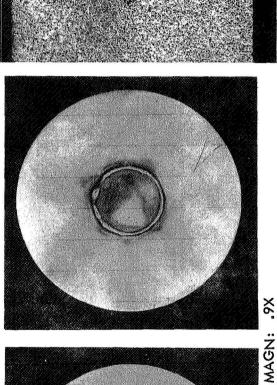


FIGURE 11 SURFACE APPEARANCE AND MICROSTRUCTURE OF ELECTRON BEAM WELDED 1/4-INCH THICK, 40% POROUS STAINLESS STEEL WIREFORM PARTS TO WROUGHT SAMPLE HOLDER



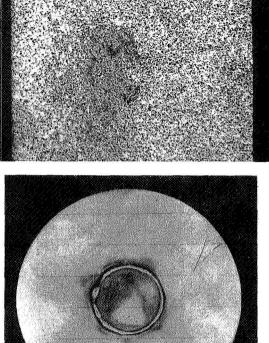


FIGURE 12 SURFACE APPEARANCE AND MICROSTRUCTURE OF ELECTRON BEAM WELDED 1/4-INCH THICK, 40% POROUS STAINLESS STEEL POWDER PARTS TO WROUGHT SAMPLE HOLDER

MAGN: 10,8X

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